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OBSERVATIONS OF THE POLAR IONOSPHERE IN THE ALTITUDE RANGE 2000 TO 3000 KM BY MEANS OF SATELLITE BORNE ELECTRON TRAPS

J. L. DONLEY

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OBSERVATIONS OF THE POLAR IONOSPHERE IN THE ALTITUDE RANGE 2000 TO 3000 KM BY MEANS OF SATELLITE BORNE ELECTRON TRAPS

by

J. L. Donley
Laboratory for Space Sciences
NASA Goddard Space Flight Center

ABSTRACT

Measurements have been made of electron density and temperature and quasi-energetic electron flux by means of planar electron traps employing retarding potential techniques on the Explorer XXXI (DME-A) spacecraft in the altitude range of from 2000 to 3000 km during magnetically quiet periods of December 1965 and January 1966.

Observations above 60^{O}N magnetic latitude indicate very low ambient electron densities (N_e<100/cm^3) which are a typical feature of the polar ionosphere at high altitudes. Irregularities and peaks of enhanced ionization are observed. These peaks have widths of up to 1000 km and contain density enhancements on the order of a factor of ten above ambient background. Within the peak there is a change of ionic composition to heavy ions (O^+) from the background composition of light ions (H^+). Comparison of Explorer XXXI electron density measurements for the very low density conditions and simultaneous density measurements from the Alouette II topside sounder experiment show excellent agreement.

INTRODUCTION

The Explorer XXXI (Direct Measurements Explorer) Satellite was launched along with the Alouette II Topside Sounder Satellite on November 29, 1965 into an 80^{o} prograde polar orbit with a perigee of 500 km and an apogee of 3000 km. The close proximity of the two spacecraft provided an excellent opportunity for simultaneous data coverage for several months after launch.

Explorer XXXI was instrumented with ionospheric direct measurement probes which provided redundant measurements of the major ionospheric parameters through different techniques. The experiments included planar ion and electron traps, cylindrical electrostatic probes, spherical ion probe, planar Langmuir plate, high resolution magnetic ion mass spectrometer, and quasi-energetic electron current monitors. The satellite had a magnetic aspect control and spin system which allowed complete orientation control of the spacecraft spin axis. The spin axis attitude was maintained normal to the orbital plane and thus all sensors mounted normal to the spin axis looked forward once each roll period of about 20 seconds.

Data from the planar electron trap and electron current monitor experiment will be presented. The electron trap consists of a target electrode located behind an aperture assembly mounted approximately flush with the spacecraft surface. The aperture assembly was about three inches in diameter with a one inch opening covered with a tungsten mesh. A staircase voltage which varied from -5 to +4 volts in four seconds was applied to the aperture assembly. The quasi-energetic electron current monitor sensor consisted of a grounded aperture grid of one inch diameter, a retarding grid, a screen grid, and target. The retarding grid received sixteen voltage steps of from -.5 to -200 volts in sixteen seconds.

DATA

Passes over the northern polar regions during magnetically quiet periods of December 1965 and January 1966 were selected.

For the days selected the three-hourly K_p index did not exceed 2. The altitude range of the passes was from 2200 km to 3000 km and the local time coverage was from about 0500 to 1900 hours.

For the months of December and January the satellite orbit was in 100% sun light. Since both the electron trap and current monitor sensors are subject to photoemission effects from the grids and this unwanted signal component masked the desired signal, only data when the sensors were directed away from the sun can be utilized when electron densities are low. In addition, electron trap data was selected only for forward looking conditions in order to be free of satellite wake effects.

Figure 1 shows a typical computer output plot of electron trap current versus retarding voltage. This particular data was taken on 14 December 1965 at an altitude of 2985 km and at 56.6^{o}N magnetic latitude. The vertical scale covers five decades of current from 10^{-11} amperes to 10^{-6} amperes. For analysis of such data it is necessary to subtract the "tail" current component (the portion to the left in the figure) from the total measured current. For this purpose it is assumed that the total measured current in the retarding potential region is the sum of a background current due to supra-thermal electrons and a Maxwell-Boltzmann distribution of lower energy thermal particles. The correction and resultant curve is shown in the figure. The slope of the curve is a measure of electron temperature and the current at the "break" point is related to the electron density. For this curve the resultant represents a density of 110/cm^3 at a temperature of 5000^{o}K. All of the data analyzed for the high altitude polar regions has been treated in this manner.

Figure 2 is a plot of electron density and temperature versus magnetic latitude for three Explorer XXXI passes. The McIlwain L parameter is also indicated. The altitude range of the data is from 2880 to 3000 km and the local time of the

December passes is 1730 to 1900 hours and from 0445 to 0515 for the January data. The density shows a decrease of from about $2000/cm^3$ at mid-latitudes to less than $50/cm^3$ at high latitudes. The electron temperature shows an increase from about $4500^{o}K$ at mid-latitudes to a maximum of about $6000^{o}K$ and then a decrease to about $4000^{o}K$ at the time of the low densities. The A on the figure at about $70^{o}N$ latitude is a simultaneous measure of electron density from the topside sounder of Alouette II using the resonance beat method of Hagg (1967) and indicates excellent agreement with electron trap values.

The decrease in density is undoubtedly a high altitude extension of the main "trough" observed by Muldrew (1965) to be a permanent feature of the high latitude ionosphere at F-layer altitudes. In summarizing Alouette I results, Chapman (1966) pointed out that at 1000 km a deep trough is a regular feature of the ionosphere located at about $60^{o}N$ magnetic at midnight moving out to about $73^{o}N$ at 1400 hours. The general behavior of electron temperature and density shown in the figure agree with that reported by Brace et al (1967) for ionospheric behavior at 1000 km in the 1964 winter solstice period. Nelms and Lockwood (1966) have reported on Alouette II data for the same period of time and the rapid decrease of density with increasing latitude is evident on all the reported passes.

Figure 3 is a measure of the current of quasi-energetic electrons with energy greater than 35ev as determined by the electron current monitor experiment. This data is the background energetic electron component corresponding to the data of figure 2. A current value of 10^{-11} ampere corresponds to an omnidirectional flux value of approximately $2x10^7/cm^2sec$. The flux remains essentially constant over most of this latitude range. There is an increase at geomagnetic latitudes greater than $70^{O}N$ (corresponding to an L value of about 15).

Figure 4 shows electron density and temperature values for selected December and January passes in the latitude range from about 55°N up to the magnetic pole. Data included in this figure cover the altitude range of from 2450 to 2930 km and local time from 0900 to 1600 hours. Alouette II topside sounder data points are indicated for comparison purposes. As in figure 2 the main trough is evident, represented by a density of about $100/cm^3$ at about 70°N corresponding to an L value of about 13 and an invariant latitude of about 74°. To the north of the trough there is a sharp increase in density followed by a second trough with densities of about $50/cm^3$ near the "pole". The polar "peak" has densities up to about $1500/cm^3$ and is located from 75°N to 81°N. The data forming the peak was taken at an altitude of about 2500 km at a local time of 0900 hours. The width of the peak at satellite altitudes is on the order of 1000 km. The center of the "peak" is located at 78°N magnetic or about 80° invariant latitude. Measurements by the high resolution mass spectrometer on Explorer XXXI indicate that the dominant ion in the peak is O^+ while the dominant ion to each side is H^+ (Hoffman).

The electron temperatures reach a maximum of 6000-6500°K shortly before the main trough, decrease to 3000-4000°K in the trough, increase to about 5500°K before the ionization peak, and decrease to a minimum value of about 2500-3000°K in the second trough.

A similar behavior of the polar ionosphere has been noted by Thomas et al (1966) using Alouette I data at 1000 km in the winter of 1962. The density in the polar peaks may exceed the mid-latitude value. Peak to trough ratios of 25 to 1 were observed with the largest peaks occurring at magnetic noon. The peak location was 77°N invariant latitude (L=25) in the morning and at 78°N invariant (L=27) in the afternoon. The main trough location was 58°N invariant (L=4.2) in the AM and 70°N invariant (L=10) in the PM. Also very low electron densities between the peaks and near the magnetic pole were noted. This same pattern is certainly present at 2500 km in the present data. Calvert (1966) using Explorer XX (Fixed Frequency Topside Sounder) data reported regions of enhanced densities and scattering irregularities with about 5° latitude width in the polar ionosphere. The southern boundary of these regions was between 70° to 80° magnetic with the lower latitudes observed at night. Lund et al (1967) have also reported on polar irregularities with a southern boundary of 75° invariant at magnetic noon from Explorer XX data which correlate with simultaneous auroral backscatter measurements. The boundary of these regions agrees well with the present data. Nelms and Lockwood (1966) have reported polar peaks in excess of $500/cm^3$ using December and January Alouette II data. However these peaks were not evident on all passes.

The fact that the polar peak is a region of irregularities is evident in figure 5 which shows two plots of electron trap data taken on 16 December. The first plot at 72.6°N magnetic is in the trough region and the second plot at 75.5°N magnetic is in the polar peak region. The jagged nature of the second plot is evidence of temporal or spatial irregularities and fine structure within the peak region.

Figure 6 is a plot of background current due to electrons with energy greater than 35ev corresponding to the data shown in figure 4. An increase of flux is noted corresponding to the region of the polar density peak. The peak current measured corresponds to an omnidirectional flux intensity of about $5x10^8/cm^2$ sec. It thus appears that the density peak is caused by an increased flux of quasi-energetic electrons causing ionization at much lower levels of the ionosphere which diffuses upward. The fact that the dominant ion present at 2500 km in the peak is 0^+ indicates that the ionization source is at low altitudes. The increase in electron temperature at the southern boundary of the density peak may be the result of selective electron heating by an increased quasi-energetic flux which starts to rise at latitudes lower than the density peak.

DISCUSSION

The data presented have linked the polar ionosphere peak to an increase in quasi-energetic flux. Thomas et al (1966) have suggested that the peak is due to ionization produced in the lower F-region by energetic electrons which have been accelerated along neutral lines in the magnetosphere and precipitated into the earth's atmosphere. Calvert (1966) commenting on the polar irregularities region has indicated that these features appear to mark the edge of a virtually separate ionosphere, since the southern boundary of irregularities marks the division between magnetospheric field lines which rotate and those which are swept back over the pole into the tail. Williams and Mead (1965) have indicated a northern limit of trapped electron with energy greater than 280 kev at 69° invariant at 1200 hours. The average noontime high latitude cutoff for electrons with energy greater than 40 kev is in the range 74° to 76° invariant (McDiarmid and Burrows, 1964). It is clear that the polar peak and associated flux is well above these limits of trapped radiation.

The magnetospheric model of Williams and Mead (1965) indicates that the dayside position of the "critical latitude", separating field lines that pass back over the pole into the tail region, is at about 82°, which is somewhat higher than the polar peak location. This could indicate that the source of flux is not the tail "plasma sheet" reported by Bame et al (1967). Also the plasma sheet was not detected at high latitudes ($\lambda > 40^{\circ}$) and any electron population present has energies and/or densities too low to be observed by the Vela satellite analyzers. McDiarmid and Burrows (1965) have reported high latitude electron "spikes" with widths up to about 2^{o} of electrons with energies greater than 40 kev. Approximately 95% of the events were observed on the nightside of the earth and no events around local noon.

These particle observations along with the observations of Thomas et al (1966) that the largest polar peaks at 1000 km occur at noon would suggest that the ionization source is not related to the plasma sheet in the magnetospheric tail but related to solar wind particles entering the earth's atmosphere along neutral lines in the magnetosphere.

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FIGURE CAPTIONS

FIGURE 1 Computer plot of typical electron trap data for low density ($N_e \sim 100/cm^3$) high latitude conditions.

FIGURE 2 High latitude electron density and temperature measured by the electron trap experiment on the Explorer XXXI satellite.

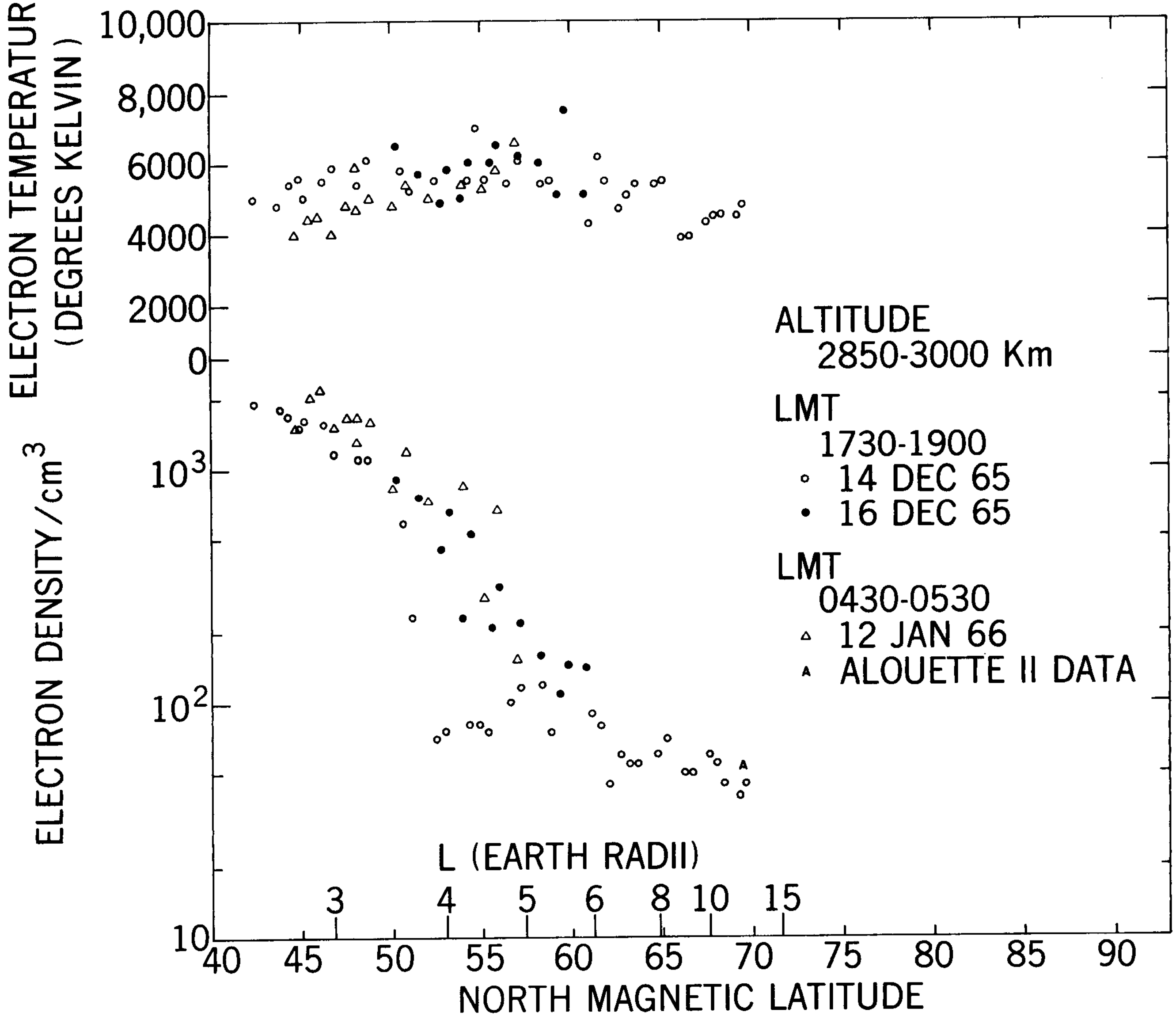
FIGURE 3 Current due to electrons with energy greater than 35ev measured by the electron current monitor experiment corresponding to the data of figure 2.

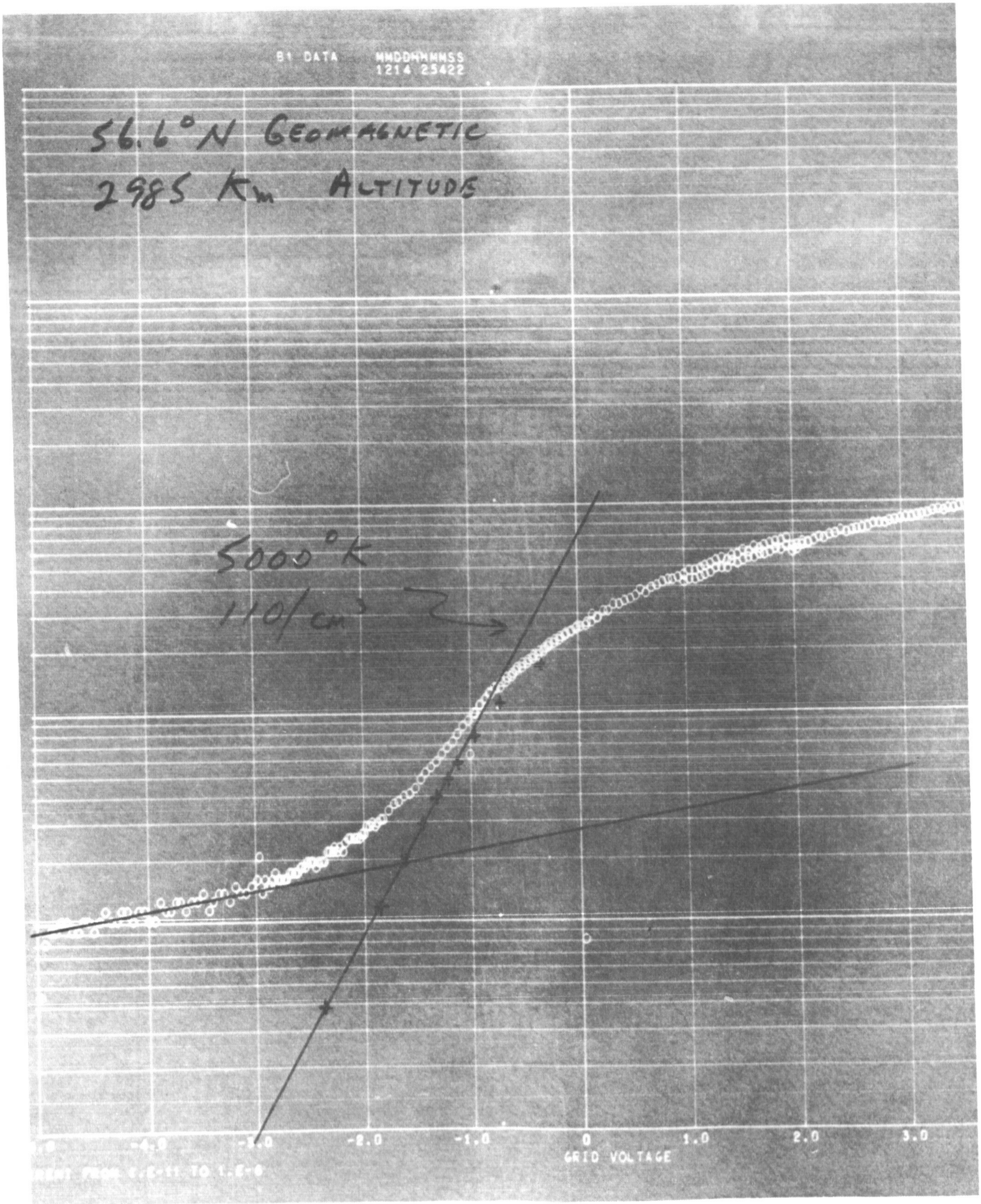
FIGURE 4 High latitude electron density and temperature showing the polar "peak" of electron density.

FIGURE 5 Comparison of electron trap data in the "trough" and "peak" regions.

FIGURE 6 Current due to electrons with energy greater than 35ev corresponding to the data of figure 4.

EXPLORER XXXI ELECTRON TEMPERATURE AND DENSITY





B1 DATA MMDDHHMMSS
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56.6°N GEOMAGNETIC
2985 Km ALTITUDE
5000°K
110/cm³
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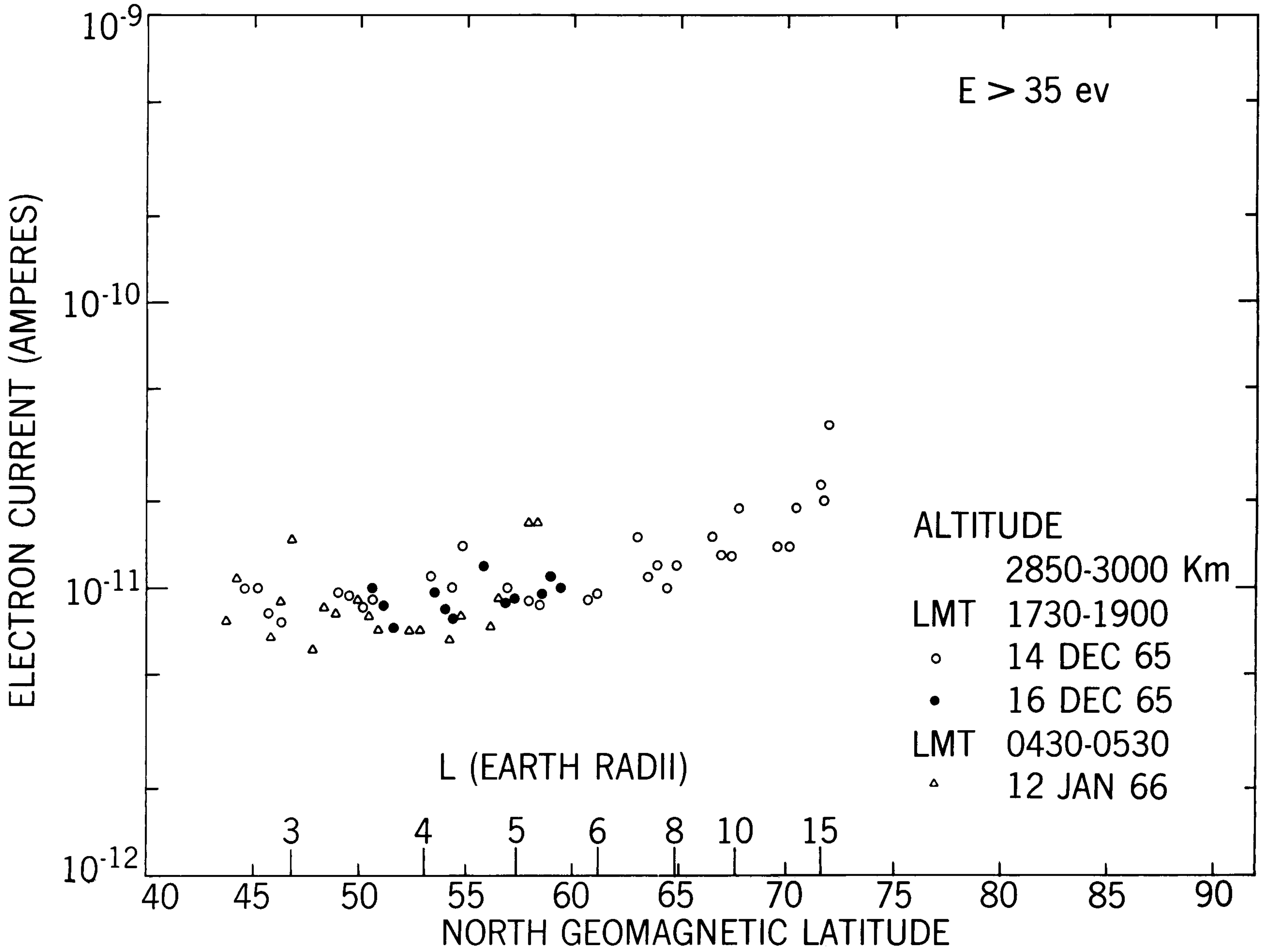
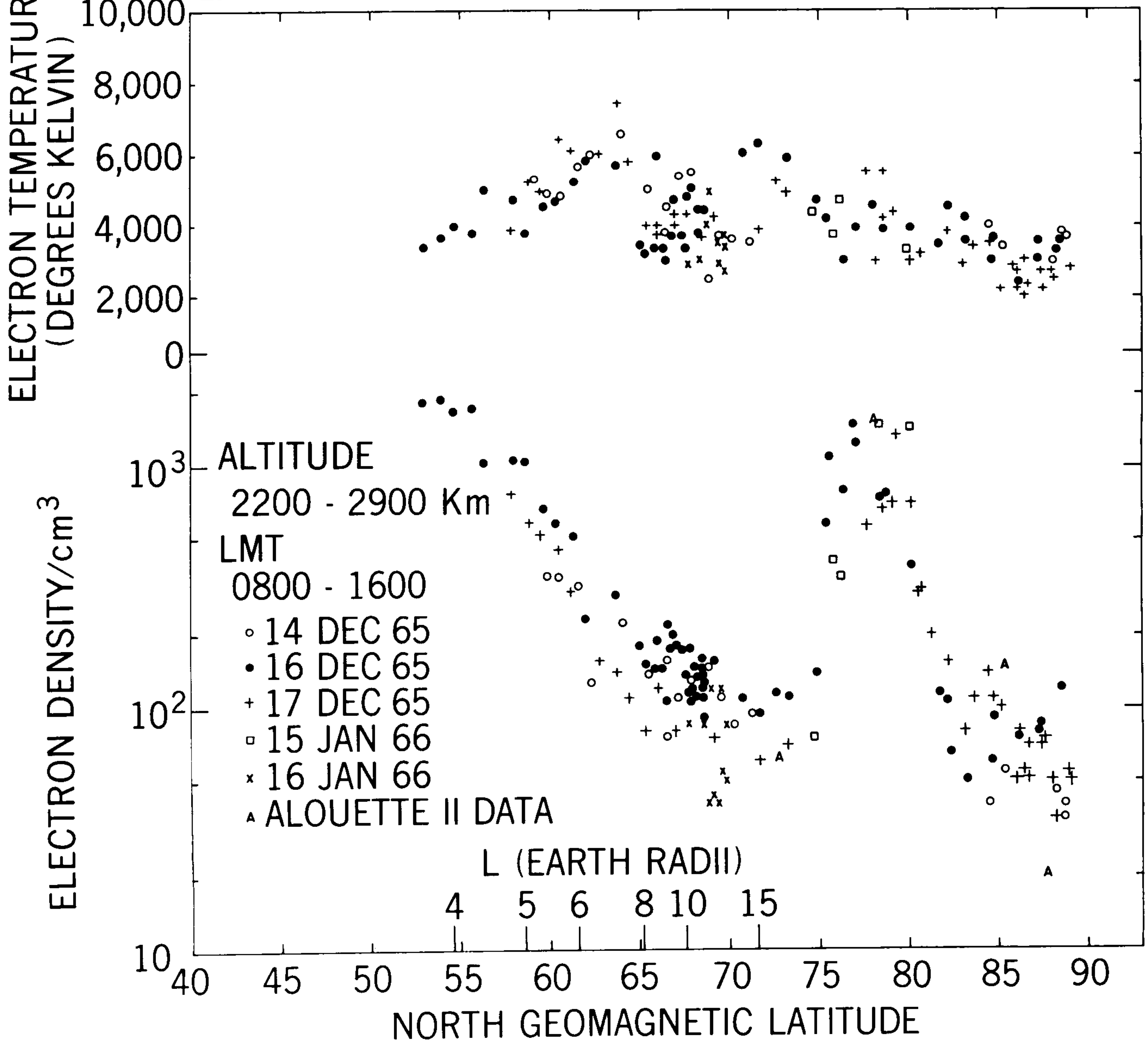
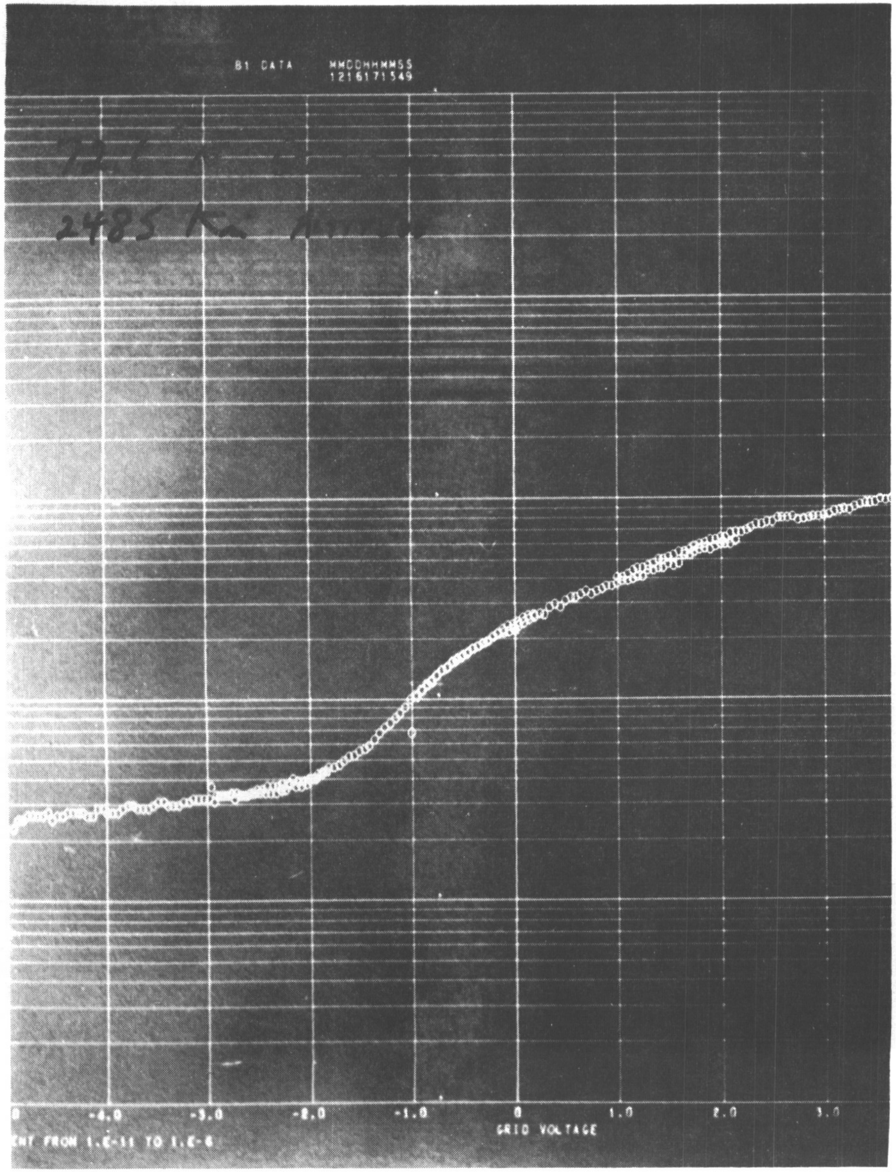
-2.0
-1.0
0
1.0
2.0
3.0
GRID VOLTAGE

EXPLORER XXXI ELECTRON CURRENT MONITOR



EXPLORER XXXI ELECTRON TEMPERATURE AND DENSITY

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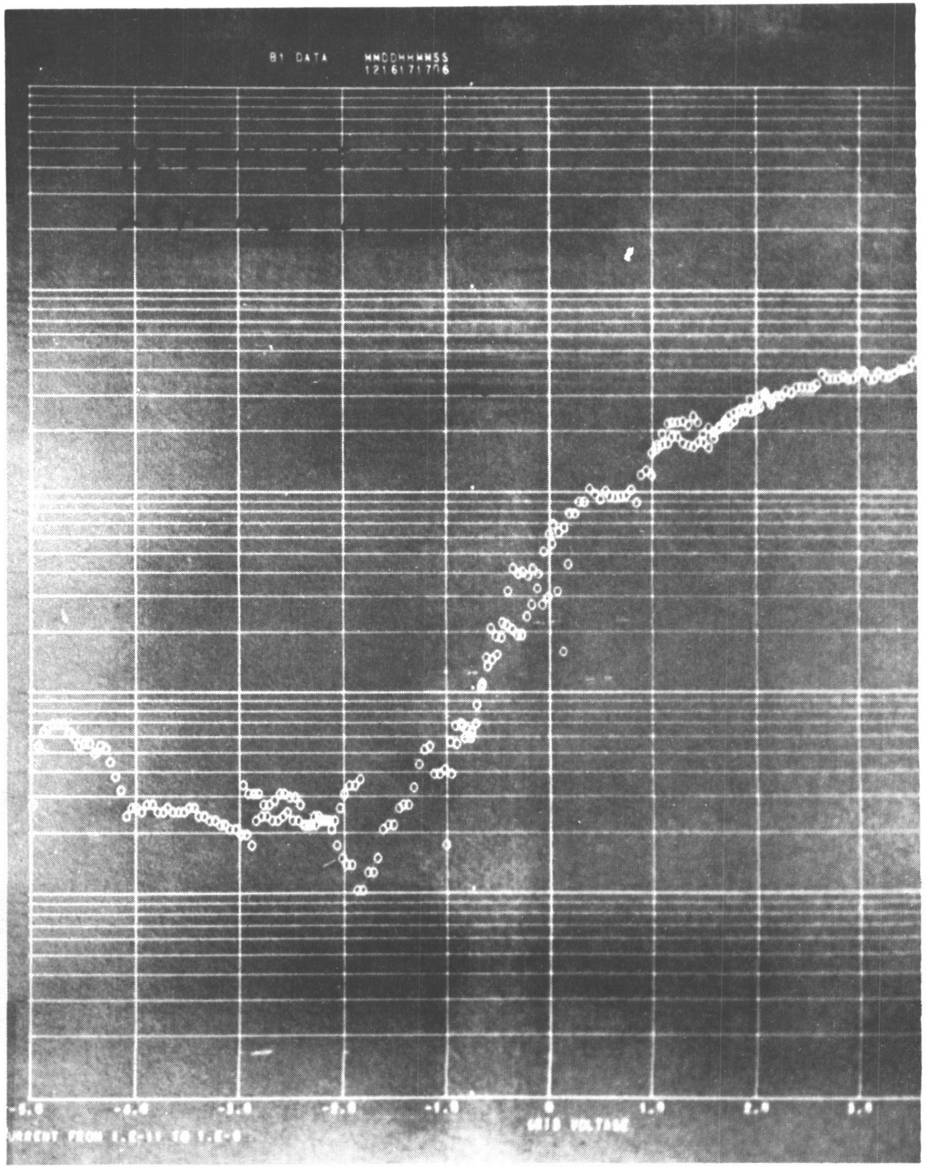
GRID VOLTAGE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GRID VOLTAGE
URRENT FROM 1.E-11 TO 1.E-6

EXPLORER XXXI ELECTRON CURRENT MONITOR